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Comprehension and Memory of Spatial and Temporal Event Components

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14. ABSTRACT *(Maximum 200 words)*:

Across three experiment series, we assessed how people update mental representations of events (called situation models). The first series decomposed spatial and temporal updating with people reading texts. These components involved (a) processing shift signals, (b) establishing new frameworks, (c) maintaining relevant objects, and (d) removing irrelevant objects. We observed component independence. The second and third series assessed cognition as people moved through virtual spaces. In the second series, we found that information about objects was less accessible when there was a spatial shift, particularly for objects the person was currently carrying. This suggests that people operating in complex environments, such as urban battlegrounds, can be negatively affected by the structure of those environments and their interaction with them. For the third series, people first memorized a map of a building. Then they navigated a virtual simulation of the building and were probed with object name pairs. We observed that memory for objects in a person's current location was more available. Second, memory for objects along pathways, that a person passed through but did not interact with, was suppressed. These findings suggest that some prior knowledge of environments may actually be less available by the very act of navigating that space.

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COMPREHENSION AND MEMORY OF SPATIAL AND TEMPORAL EVENT COMPONENTS

EXECUTIVE SUMMARY

Research Requirement:

This research explores the ability of people to update their understanding of situation and event information as they are dynamically unfolding, either in linguistic descriptions or interactive virtual reality simulations. The particular focus is on updating spatial (moving to a new location) and temporal changes (a switch in the time frame, such as a day later). For assessing language comprehension, updating was broken down into various mental components. Another line of work looked at the ability of a person to update their understanding of an ongoing event where there has been a change in the spatial location in an interactive environment. Finally, a third line of work followed on a finding in narrative comprehension that information about objects in a known location becomes less available in memory the further it is from the story protagonist's current location (a spatial gradient). The current research assessed whether interactive events would show a similar pattern as a person moved through a previously learned space. This is important because much of the work done on event cognition has focused on language comprehension, not on interactive environments. Knowledge of this process can provide insight into ways to provide training to help avoid any cognitive difficulties, and to design systems that take into account the cognitive limitations of the user as new event information is acquired as the dynamic situation unfolds around them.

Procedure:

In the first series, people were presented with passages to read on a computer. These passages contained critical sentences in which a spatial or temporal shift either did or did not occur. Prior to each critical sentence was a sentence that mentioned a critical object. Afterward a probe was presented and people indicated whether it had occurred earlier in the passage. The probe could refer to the new event framework (e.g., the name of the new location) or to the object in the prior sentence. People responded by pressing one of two buttons on a computer mouse. Reading times were used to determine the degree to which cognitive processing was affected by a signal to update one's understanding of the event by establishing a new mental framework of the new spatial location or time frame. Response times to probes were used to make comparisons that involved the various probes when a spatial or temporal shift had occurred relative to a control condition in which there was no-shift.

In the second series, people navigated in a virtual environment. The task was to pick up an object in one room and move it to another. At critical points, people were probed with object names. These object names were either the one that they were currently carrying (associated), the one they had just set down (dissociated), or some other object (filler). The task was to respond "yes" to the names of objects in the associated and dissociated conditions, and "no" to the fillers. Response times and error rates were recorded.

In the third series, people memorize a map of a building, including the names of the rooms as well as the objects within them. After memorization, people navigated a virtual environment of the building. The task was to move from room to room as instructed. At critical points, people were probed with pairs of object names. The task was to indicate whether the two objects were in the same room together. The critical variable was the distance of those object pairs from the person's current location. Response times and error rates were recorded.

Findings:

There were a number of key findings from this research. For the first (language comprehension) series, people were successful at updating their understanding of an event following a change in space or time. When there is a shift to a new spatial location, people were facile at making this transition, whereas shifts in time require more effort. The ease with which spatial shifts are made is supported by the finding that people are able to remove information about newly irrelevant entities from their current stream of thought. The difficulty people have with a shift to a new time frame was accompanied by a decreased ability to remove information about newly irrelevant objects.

For the second series (moving objects in virtual reality), information was less available about objects that were dissociated from a person than objects that were associated. More importantly, the act of moving from one location to another disrupted the ability to track information about objects, especially those that were currently being carried (and so most relevant). This cognitive disruption was reflected in both the response times and, more importantly, the error rates of people's responses.

For the third series, information about objects that were in the current location was readily available, but information about objects along a pathway was hindered in memory, making it more difficult for people to use this knowledge when called upon. The suppression of pathway information took time to develop and continued to emerge after a person had arrived at his/her destination.

Utilization and Dissemination of Findings:

The research reported in the first series suggests that Soldiers are most likely to have difficulty when they need to adjust to a new time frame when linguistically processing event information. It is recommended that Soldiers be explicitly reminded that information about those entities from a prior, but no longer operating, time frame is no longer relevant. For example, a Soldier who is told that an ammunition truck was in the area a day ago may implicitly assume it is still there even though there would be good reason to know that it no longer was. As such, the Soldier may make plans that depend on the truck being present, only to later find out that it is not.

The research reported in the second and third series suggests that Soldiers will have difficulty processing information when they move from one location to another, in terms of the ability to remember currently relevant aspects of the situation, as well as information about objects that are along traveled routes (other than the starting and goal locations). Because of the

need to operate in urban environments where spatial changes are frequent, a better understanding of these phenomena, and the cognitive mechanisms that underlay them, can be useful it training a fighting force that will ultimately be less affected by these mind-environment interactions.

Further work is needed to assess whether this sort of situational awareness can be augmented through training efforts that explicitly point out these sorts of errors. As technology develops to interact with the modern Soldier, this technology needs to keep track of what a given Soldier may or may not be actively thinking about. While there are many pieces of information that may be useful to the Soldier, because of working memory limitations, the Soldier can easily be overwhelmed with irrelevant information. As such, the information that is presented should be information that is likely to be of use. This sort of research helps identify critical types of information that would be helpful to present to help compensate for known difficulties that occur when processing information about events.

COMPREHENSION AND MEMORY OF SPATIAL AND TEMPORAL EVENT COMPONENTS

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Decomposing Spatial and Temporal Narrative Event Shifts

Abstract

People comprehending language need to update their understanding of ongoing events (their situation models) as the described circumstances change. Two experiments attempt to decompose the cognitive components involved in this updating process after spatial and temporal event shifts, and to assess the interrelations among those components. These components involve (a) the processing of situation shift signals, (b) the establishment of a new situation framework, (c) the maintenance of relevant entities, and (d) the removal of newly irrelevant entities. While there was some evidence to suggest that processing changes along one component were indicative of changes along another, there was independence of influence. Moreover, spatial and temporal updating appear to proceed very differently in cognition, with some measures showing strong effects for one dimension, but having no influence on the other. Thus, when Soldiers need to process information about changes in time and space, this will involve distinct mental activities that are not dependent on one another.

Introduction

When people comprehend language, the events being described are often dynamic. For example, Soldiers operating in the world have to understand the current set of circumstances and to adjust their understanding as they learn new information about how the situation has changed. Various components of the events are changing, and to successfully comprehend the description, people need to be able to accurately update their situation models (Johnson-Laird, 1983; Van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998) to capture these changes. The aim of this research was to explore the cognitive components that could be involved in this sort of updating; the degree to which those components are involved in two types of updating, namely spatial and temporal; and to assess the degree to which the influence on processing of one updating component influences the processing of other components.

Research in language comprehension has identified three levels of representation: (a) the surface form, (b) the textbase, and (c) the situation model (Johnson-Laird, 1983; Kintsch, 1998; Schmalhofer & Glavanov, 1986; Van Dijk & Kintsch, 1983). The *surface form* is the actual words and syntax used in a text. The *textbase* is the set of abstract ideas derived from the surface form. Finally, the *situation model* is the information in the textbase along with those inferences drawn using knowledge of how situations and events are structured in the world. A situation model is a representation of a described situation (Johnson-Laird, 1983; Kintsch, 1998; Radvansky & Zacks, 1997; Van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998) that serves as a mental simulation of the context, events, entities, and relations involved in a state of affairs. Although situation model construction may use more general semantic information, such as schemas and scripts, they are not simply instantiated versions of these described situations. Instead, they are unique configurations of information to represent a unique event, which may or may not be highly schematic.

Situation model updating is a cognitively effortful process. For example, when people read texts in which a situational shift occurs, along any one of a number of dimensions, there is a

measurable increase in reading time (e.g., Zwaan, Magliano, & Graesser, 1995; Zwaan, Radvansky, Hilliard & Curiel, 1998). This increase in mental effort is observed because of a need to update one's understanding of the situation to incorporate the new facts. This updating creates breaks in the understanding of a developing situation and can be further revealed in memory performance. For example, if people are asked to sort verbs from a previously read story into piles, they tend to put verbs on different sides of a situational break into different piles (Zwaan, Langston, & Graesser, 1995).

Each situation model of an event is grounded in a spatial-temporal *framework* (Wyer & Radvansky, 1999). During comprehension, people need to monitor spatial location and time frames. There is substantial evidence that framework information is an effective means of organizing information in situation models, and that this has a meaningful influence on cognitive processes as reflected by reading times (e.g., Morrow, Greenspan & Bower, 1987) and interference effects in memory retrieval (e.g., Radvansky, 1999). The current research focuses on these spatial and temporal updating processes.

Components of Situation Model Updating

The aim of this research was to assess the cognitive components involved in mental updating when there has been a change in spatial or temporal location. Updating is viewed as involving four components: (a) processing a shift signal, (b) establishing a new framework, (c) carrying over relevant entities from the prior framework to the new one, and (d) removing newly irrelevant entities from the focus of the model.

Shift Signal Processing

Shift signal processing was measured by looking at reading times for sentences containing shift information. These are sentences in which a shift from one spatial or temporal framework is clearly indicated. Research on spatial and temporal shifts has shown that, on some occasions, sentences describing a move to a new spatial location can result in an increase in reading times (e.g., Zwaan, 1996; Zwaan et al., 1998). For a given critical sentence, there were two versions. In one version a spatial or temporal shift occurred, whereas in the other it did not. Evidence of the influence of the detection of a shift on processing is reflected as a reading time difference in these two conditions. Essentially, longer reading times are interpreted as an increase in cognitive effort triggered in response to the shift signal. In the work reported here, this concept is extended to interactive events with real changes in space and time.

New Framework Establishment

New framework establishment was measured by looking at the availability of information pertinent to the new framework relative to the old. When a shift occurs, information that defines the new framework should be more available than the old one (e.g., Morrow et al., 1987). For spatial shifts, the spatial location can often be identified with a label that applies to that region, such as "living room." In comparison, for temporal shifts, although it is possible that we can label a time frame, such as "1:00 p.m.," this is not a common way to refer to periods of time in narratives. Furthermore, memory for absolute time (that is, when events occur) is quite poor

(Friedman, 1993; Radvansky, Zwaan, Curiel, & Copeland, 2001). Instead, time intervals are defined by the activities that people are involved in. For example, watching a movie is an activity that defines a period of time. Research on temporal shifts has shown that this kind of time frame-identifying information is less available when there has been a shift in time (Zwaan, 1996).

For the current research, the shift from an old framework to new one was assessed by looking at the availability of framework identifying information as a function of whether a shift had occurred or not. The processing of spatial shifts was assessed by looking at response times to location name probes (e.g., "Chicago"). The processing of temporal shifts was assessed by looking at response times that refer to the protagonist's activity (e.g., "painting") (Zwaan, 1996). In both cases, availability of these concepts was assessed using response times and error rates to memory probes as a function of whether a shift had occurred.

Object Maintenance

Object maintenance was measured by looking at the availability of information about an object that should remain relevant after a shift, relative to when there was no shift. These entities are ones that are in the original situation and are brought along to a new one. For example, if a person has been given a letter in one location, and then moves to a new location, information about the letter should remain available. Research on spatial shifts has shown that object information remains stable following a spatial shift (e.g., Glenberg et al., 1987). There are currently no studies addressing the availability of object information following a temporal shift, but the principle should be the same. So, for example, if a person places a credit card in his/her wallet, the credit card is still likely to be there a day later.

If updating is successful, then relevant information should be maintained and carried across to the new framework. This was tested by looking at response times to object name probes (e.g., "letter") that had been introduced prior to spatial or temporal shifts, as a function of whether there actually was a shift or not. If the information is maintained, availability should not change, as would be evidenced by a significant interaction compared to object removal (see below).

Object Removal

Object removal was measured by looking at the availability of newly irrelevant object information after a shift. Newly irrelevant information would correspond to objects that are relevant in the context of the original framework but not in the new one. For example, if a person sets a box down in one location, and then moves to a new location, information about the box should be less relevant. If updating proceeds appropriately, then newly irrelevant information should not be carried over to the new framework. Research on spatial updating in narrative comprehension has shown that when a person moves from one location to another, objects associated with the old location become less available (Glenberg et al., 1987). As with the object maintenance issue, there has been no research directly testing the availability of objects across time shift boundaries.

Object removal was tested by looking at response times to object name probes (e.g., "box") when there was a shift versus when there was not. To emphasize the distinction between object removal and maintenance, in the former condition the object is not relevant to the new situation, and in the latter condition the object is relevant to the new situation.

Experiment 1

For Experiment 1, people were given a series of texts to read. These texts described the movement of people from one spatial location to another. Previous research using reading times to assess the processing of spatial shifts has shown that people are more likely to attend to spatial information and process spatial shifts when the set of locations is already familiar (Zwaan et al., 1998). For this reason, the names of well-known cities were used. During reading, people were interrupted with memory probes composed of one or two words. The task was to indicate whether the probe had occurred earlier in the passage.

Method

Participants. Sixty-nine people participated in Experiment 1. They were recruited from the subject pools at the University of Notre Dame ($N = 37$) and Indiana University South Bend ($N = 32$). These people were 18 to 30 ($M = 20.2$) years of age and were given partial course credit for their participation.

Materials. For Experiment 1, people read eight stories. Each story was 43 to 61 sentences long. A sample story, along with sample probes, is shown below and their respective conditions.

Going Home

She had been living here for 4 months. Now Mary Agnes had to go home. She had been living abroad with her uncle. But it was only for one semester. Now she had to go back to her school in the Midwest. She hated packing up and going. But she had to do it. She was in the bedroom putting some of her things in boxes. Mary Agnes saw a book she had recently bought. She bought it with her friend Bridgette. She picked the book up and went into the study. [**PROBE** BOOK (object maintenance)] She was sure she had seen another copy here in the house. Darren was already in the study. He was sitting in the leather chair listening to some music. [**PROBE** LAMP (filler)] He had headphones on, but Mary Agnes could still make out the lyrics. She shook her head. She scanned the shelves, but couldn't find what she was looking for. However, she did see a book on Italy. That reminded her about the wine she had bought. She thought about leaving the study to go into the kitchen to get it. [**PROBE** KITCHEN (no-shift)] A minute later Uncle Samuel poked his head in the door. He asked Mary Agnes if she had seen his reading glasses. She said no, and asked him if he had seen her wine. He said that he had. And he had been eyeing it with jealousy. [**PROBE** PICTURE (filler)] Mary Agnes laughed at this. She finished what she was doing and went into the dining room. She needed to double check what she had in her purse. This was the only room with a table big enough to lay it all out. [**PROBE** DESK (filler)] 'I really need to get a smaller purse', she thought. Mary Agnes noticed her brush was missing. She remembered that she had left it in the car. She left the dining room and walked into the garage to get it. [**PROBE** GARAGE (shift)] Walking into the downstairs bathroom she noticed something. A brochure from a camp they had visited. Mary Agnes looked it over and

remembered the trip. She smiled when she remembered tricking Darren. [**PROBE** PORCH (filler)] Then she frowned when she remembered how he got back at her. He had packed all of her underwear into the freezer. Mary Agnes glanced at the brochure a little more. Then she put it back down. She stopped at the sink. [**PROBE** BROCHURE (neutral)] She gazed at her face in the mirror. It looked so pale. Behind her she saw a shirt hanging on a hook. She had bought it a month ago, and she looked good in it. [**PROBE** BASEMENT (filler)] She thought she should wear the shirt on the plane flight. Then she'd look better when Donny met her there. He was the one thing she really missed on this trip. She left the shirt on the hook. She was done in the bathroom, so she went down to the laundry. [**PROBE** SHIRT (object removal)]

Included in each story were six critical spatial shift sentences in which a character went from one place to another. In half of the critical sentences, there was an actual spatial shift. In the remaining critical sentences there was no spatial shift; the new spatial location was mentioned, but the character did not move to it. Thus, for each story, three of the critical spatial shift sentences had a spatial shift and three did not. There were different versions of each story so that difference probes and conditions were counter-balanced across subjects in the different probe locations within a story.

Prior to each critical spatial shift sentence, there was also a critical object sentence. For three of them, the object was picked up by the protagonist. In the remaining three, the object was set down. Combined with either a spatial shift or not, this made for three object conditions. When the object was picked up and there was then a spatial shift, this was an Object Maintenance condition, because the object was to be maintained across the spatial shift. When an object was set down and there was then a spatial shift, this was an Object Removal condition, because the object was to be removed from the situation model. When the object was either picked up or set down but there was no spatial shift, there was no reason to expect any change in the availability of this knowledge.

Procedure. At the beginning of the testing session, a brief description was provided and then people were given a consent form to sign. Following that, the experiment was conducted using E-prime software. Each story was presented, one sentence at a time, on a computer monitor. At the beginning of each story, a title for the story was presented in a yellow font. People advanced through the stories by pressing the space bar with their left land on the keyboard. Reading times were recorded.

At predetermined locations within the story, a probe was presented. The probe appeared when the person pressed the space bar after reading the prior sentence (the subject did not know that a probe would appear). The task was to indicate whether the probe had occurred earlier in the story. Responses were made by pressing one of two buttons on a computer mouse, held in the person's right hand. The left button was marked with a "Y" for "Yes, this probe occurred earlier in this story"; the right button was marked with an "N" for "No, this probe did not occur earlier in this story." People were encouraged to respond as fast and as accurately as possible. Response times and error rates were recorded.

At the end of each story, there were two comprehension questions. These were given to ensure that people were attending to the stories. These were yes/no questions for which people responded by pressing one of the two mouse buttons.

Results

For all of the analyses reported in this paper, a conventional level of significance of $p < .05$ was used, and, consistent with the practice in the field, results of $.05 > p > .10$ were considered marginally significant. Power analyses also are reported for those critical effects that did not reach significance.

Spatial shift signal. To assess whether the presence of a spatial shift signal influenced processing, reading times were examined for critical spatial shift sentences that either contained a spatial shift or did not. These reading times were divided by the number of syllables to account for length. The results showed that reading times did not differ when there was a spatial shift (M = 163 ms/syl; SD = 44) from when there was not (M = 165 ms/syl; SD = 43), $F(1, 68) = 1.56$, $MSE = 103$, $p = .22$, $Power = .85$. This is not surprising given that finding no evidence for an influence of a spatial shift in reading times is not unusual in previous studies (e.g., Zwaan et al., 1998).

New location establishment. To assess whether a person had established a new model of the new location when there was a shift, people were given probes of the critical location names; accuracy and response times were measured. The analysis of the response times showed that people were faster to respond to a location name when it was a location that a person had shifted to (M = 1007 ms; SD = 267) as compared to one that had only been mentioned, but not shifted to (M = 1055 ms; SD = 218), $F(1,68) = 8.19$, $MSE = 10078$, $p = .006$. That is, when a person had actually shifted to a location, that location identity was more available than one that had only been mentioned. This is consistent with the idea that people are updating their situation models, even though this is not reflected in the reading time data. As for accuracy, in general, people were very accurate in their ability to respond to the location name probes, both when there was a spatial shift (M = .94; SD = .10) and when there was not (M = .94; SD = .10). This difference was not significant, $F < 1$.

Object maintenance. To assess whether a person had retained access to a representation of an object that was maintained by a protagonist after a spatial shift had been made, people were given probes of the critical object names both when there was a shift and when there was not. Accuracy and response times to these probes were measured. The analysis of the response times showed no difference when there was a spatial shift (M = 1164 ms; SD = 264) as compared to when there was not (M = 1155 ms; SD = 250), $F < 1$, $Power = .85$. Thus, information was available similarly regardless of whether a spatial shift occurred. Similarly, people were accurate in their ability to respond to the object name probes, both when there was a spatial shift (M = .90; SD = .12) and when there was not (M = .90; SD = .11). This difference was not significant, $F < 1$.

Object removal. To assess whether a person had removed a representation of an object after a spatial shift had been made, people were given probes of the critical object names both when there was a shift and when there was not. Accuracy and response times to these probes

were measured. The analysis of the response times showed that people were slower to respond when there was a spatial shift (M = 1212 ms; SD = 356) as compared to when there was not (M = 1154 ms; SD = 250), $F(1, 68) = 3.55$, MSE =31862, $p = .06$. This is consistent with other studies that have shown that there is a decline in information availability following the removal of objects from the foreground of a situation model as a result of a spatial shift (e.g., Glenberg et al., 1987). People were accurate in their ability to respond to the object name probes, both when there was a spatial shift (M = .92; SD = .12) and when there was not (M = .90; SD = .11). This difference was not significant, $F(1, 74) = 1.16$, MSE = .012, $p = .29$.

Interrelations among components. To assess the interrelations among the updating components identified, we submitted the above effects to a correlation analysis, reported in Table 1.1. None of the correlations with the reading time spatial shift signal measure were significant. This is not surprising given that the signal effect itself was not significant.

Table 1.1
Results of the Correlation Analysis for Experiment 1

	Signal	NLE (RT)	NLE (err)	Maint (RT)	Maint (err)	Remove (RT)
Spatial Shift Signal						
New Location Estab. (RT)	.127					
New Location Estab. (errors)	.050	.043				
Object Maintenance (RT)	-.175	.189	-.043			
Object Maintenance (errors)	-.003	.041	-.069	.300*		
Object Removal (RT)	-.121	.029	-.283*	.359*	.155	
Object Removal (errors)	.104	.034	-.055	.298*	.315	.558*

* $p < .05$

For the location establishment measures, while there were no significant correlations with the response time data, there was one with the accuracy data, even though the accuracy effect itself was not significant when tested alone. Specifically, there was a negative correlation with the response time effect for when objects had been removed from the current situation. The smaller the error rate difference on the new location establishment effect, the smaller any influence of a removed object. In other words, people who did not establish a new spatial framework in their situation model were less likely to show a response time effect.

For the object maintenance and removal measures, in addition to the correlation of the response time and accuracy data within each of these conditions (which is of less interest), the maintenance response time effect was correlated with both the response time and error removal effects. Essentially, the more a person was disrupted in retrieving information about an object after a spatial shift, even when it was to be maintained, the greater the difficulty a person had accessing object information in general. This idea is only tempered by the absence of a correlation with the removal response time effect and the maintenance error rate effect.

Discussion

The results of Experiment 1 showed that responses were affected by the availability of spatial location information following a shift, and the availability of object information following a spatial shift as a function of whether that object was maintained or removed. Specifically, response times to location names were faster if the person had just moved to that location as compared to conditions where the location was only mentioned. In addition, when entities are maintained across a shift, there is no difference in availability compared to when no shift had occurred. In comparison, for entities that were removed from the situation, the data were in the direction of less availability, although the analyses were only marginally significant. Finally, consistent with previous work (Zwaan & Van Oostendorp, 1993), the spatial shift signal in the text did not influence reading times for those sentences.

The lack of an effect of a spatial shift on reading time but the presence of an effect on spatial location establishment is important. The lack of an effect on reading time has been interpreted as evidence against the idea that people are actively tracking spatial shifts (Zwaan et al., 1998). However, this idea is at odds with the fact that on the new location establishment task, people showed evidence that they had updated their models. A likely explanation is that people are so facile at updating spatial shifts that this does not affect reading time.

In general, it is expected that people presented with linguistic information about a change in spatial location are likely to be able to effectively process this information, although indicators of this ability may not all be revealing. Moreover, just because a person has shifted their mental framework to the new spatial location does not mean that they will be successful in appropriately adjusting the availability of objects relative to that new spatial location. Specifically, objects that were relevant in the prior location will continue to remain at a high state of availability even after they have become no longer relevant.

This is reflected in the fact that the relations between these various components were often not significantly correlated. Although there were significant relations among the object maintenance and removal measures, this is less impressive because all of these measures pertain to the tracking of objects in the situation model in addition to any influence of spatial shifts on processing. This leaves us with a significant correlation between the response time and new location establishment effect and the accuracy difference for the object maintenance effect. The fact that this is a correlation between two different types of measures (response time and error rates), the absence of a significant effect of the latter, and the absence of similar correlations with the other possible comparisons of framework establishment with object maintenance and/or removal reduces our confidence in the ability of this correlation to reflect some interesting aspect of the relation between various situation model updating components.

Experiment 2

The aim of Experiment 2 was to extend our investigation of how people process temporal framework shifts. We manipulated temporal shifts by using a paradigm developed by Zwaan (1996; Radvansky, Copeland, Berish, & Dijkstra, 2003). In this paradigm, a temporal shift is described as being either “a moment later” or “a day later.” In the context of this research, a

moment later is a very brief period of time, and is likely to be interpreted as being temporally continuous with the ongoing event. As such, no shift in the temporal framework is expected. In contrast, a day later is out of the bounds of the prior activity (e.g., being at a dinner party). As such, a temporal shift occurs. Reading time for the sentences containing the temporal shift was our measure of the processing of the temporal shift signal.

To assess whether people had established a new temporal framework, it is difficult to probe for temporal labels as was done with spatial location names. People typically do not label periods of time when discussing events (Friedman, 1993). If we were to construct narratives that had this quality, they would seem odd to most readers. So, instead, we assessed whether people had shifted to a new temporal framework by assessing the availability of activity information. These were activities that were occurring prior to the temporal shift, and in some sense help define the temporal framework (Radvansky, Zwaan, Federico & Franklin, 1998). These activities would be available after a short shift, but not after a long shift (Zwaan, 1996). Response times to these probes were used to measure temporal framework establishment.

Finally, like Experiment 1, we assessed the availability of object information as a function of whether or not it would have been carried over to a new temporal framework. The comparison condition was when there was no shift in time. Again, some of these entities were maintained across the shift, and others would need to be removed.

Method

Participants. Ninety-five people participated in Experiment 2. They were recruited from the subject pool at the University of Notre Dame. These people were 18 to 22 ($M = 19.4$) years of age and were given partial course credit for their participation. An additional three subjects were tested but removed from the analysis for failing to follow instructions.

Materials and procedure. For Experiment 2, like Experiment 1, people read a set of eight stories presented in a random order for each person. Each story was 45 to 57 sentences long. Included in each story were critical temporal shift sentences. There were two versions of each critical sentence. In the time shift version, there was a signal of a major shift in time (i.e., a day later). In the no-shift version, the time shift was relatively short (i.e., a moment) and so did not signal a major change. There were six temporal shift sentences in each story. These story versions were counterbalanced and rotated across subjects.

In addition to these time shift sentences, there were also critical probes, of which there were three versions. In one version, the probe was the activity (e.g., typing) from the prior sentence. This was an activity that would likely continue in the absence of a time shift, but would have stopped following a temporal shift. This was used to assess which people had shifted to a new temporal framework. In another version, the probe was an object that was acquired prior to the temporal shift and was likely to still be associated with the person after a day had passed (e.g., a credit card). This served as the object maintenance condition. Finally, when an object was dissociated from the protagonist prior to the temporal shift, this was considered an object removal condition. The rest of the procedure was like Experiment 1.

Results

Temporal shift signal. To assess whether the presence of a temporal shift signal influenced processing, we examined for critical temporal shift sentences that either contained a temporal shift or did not. Again, these reading times were divided by number of syllables to account for length. The results showed that people took longer to read a sentence when there was a temporal shift (M = 156 ms/syl; SD = 30) than when there was not (M = 146 ms/syl; SD = 32), $F(1, 94) = 54.95$, $MSE = 84$, $p < .001$. Thus, unlike spatial shifts, processing was sensitive to a change in the temporal framework marked by these sorts of shift signals (Zwaan et al., 1995).

New time frame establishment. To assess whether a person had established a new model of the new time frame, people were given activity probes for actions being performed prior to the temporal shift. The analysis of the response times showed that people were slower to respond when there had been a temporal shift (M = 1242 ms; SD = 410) than when there was not (M = 1175 ms; SD = 351), although this effect was only marginally significant, $F(1, 95) = 3.30$, $MSE = 64075$, $p =.07$. This is consistent with Zwaan's (1996) reported finding. In general, people were similarly accurate in their ability to respond to the activity probes, both when there was a temporal shift ($M = .80$; $SD = .15$) and when there was not ($M = .80$; $SD = .16$), $F < 1$.

Object maintenance. The analysis of the response times showed no difference when there was a temporal shift (M = 1211 ms; SD = 381) as compared to when there was not (M = 1223 ms; SD = 381), $F < 1$, *Power* = .78. When there was a temporal shift, information that needed to be maintained did not show a change in availability compared to when there was no such shift. Likewise, people were similarly accurate in their ability to respond to the object name probes, both when there was a temporal shift ($M = .86$; $SD = .12$) and when there was not ($M = .88$; $SD = .11$), $F(1, 94) = 2.35$, $MSE = .011$, $p = .13$.

Object removal. The analysis of the response times showed no difference when there was a temporal shift (M = 1214 ms; SD = 346) as compared to when there was not (M = 1223 ms; SD = 374), $F < 1$, *Power* = .64. When there was a temporal shift, information about objects that needed to be removed was not significantly reduced in availability. Analysis of accuracy to respond to entities that were part of the prior time frame, but not the current one, revealed no difference when there was a temporal shift ($M = .87$; $SD = .12$) and when there was not ($M = .88$; $SD = .11$), $F < 1$.

Interrelations among components. To assess the interrelations among the various updating components, we submitted the above effects to a correlation analysis, reported in Table 1.2. First, as with Experiment 1, none of the correlations with the reading time temporal shift signal measure were significant, even though the reading time effect was significant in Experiment 2, unlike Experiment 1.

Table 1.2
Results of the Correlation Analysis for Experiment 2

	Signal	NTE (RT)	NTE (err)	Maint (RT)	Maint (err)	Remove (RT)
Temporal Shift Signal						
New Time Estab. (RT)	-.061					
New Time Estab. (errors)	.046	.208*				
Object Maintenance (RT)	-.110	-.217*	.106			
Object Maintenance (errors)	.060	-.009	.131	.297*		
Object Removal (RT)	-.110	-.280*	-.056	.606*	.261*	
Object Removal (errors)	.019	-.048	.110	.168	.539*	.372*

* $p < .05$

For the framework establishment measures, while there were no significant correlations with the error rate data beyond the expected correlation with response time, there were two significant correlations of the response time effect with the object maintenance and removal response time effects. In general, the greater the difficulty a person had accessing information about an activity from a prior time frame, the less difficulty they had accessing information about objects after a time shift, regardless of whether the objects needed to be maintained across that shift or not. This suggests that whatever this relationship reflects, it is not due to the updating of information as a function of a temporal shift.

For the object maintenance and removal measures, in addition to the correlations of the response time and accuracy data within each of these conditions (which is of less interest), the maintenance response time effect was correlated with the response time removal effect, and error rates were correlated with both the response time and error rate removal effects. Essentially, like Experiment 1, the more a person was disrupted in retrieving information about an object after a temporal shift, even when that object was to be maintained across the shift, the greater the difficulty a person had accessing object information in general.

Discussion

The results of Experiment 2 showed that responses were affected by temporal shifts and the establishment of a new temporal framework. Specifically, people took longer to read a sentence when it contained a temporal shift. This is consistent with the idea that people need to update their understanding, and this updating takes time. Also, response times to activity names were slower if there had been a temporal shift. This is consistent with the idea that information that is relevant to a prior state of the event is less available. Activities were bound to a prior temporal framework. However, temporal shifts had no influence on the availability of information about objects, regardless of whether they needed to be maintained or removed after a temporal shift.

In terms of the relation between these various components of an event, parallel to Experiment 1, there were no significant correlations involving the reading time measure. Thus, the degree to which processing is influenced by the occurrence of a temporal shift does not affect the facility with which processing occurs for the other aspects of model updating. Like

Experiment 1, the performance involving the establishment of the new framework was significantly correlated with performance on the object maintenance and removal effects. Specifically, in both cases some component of the situation was no longer relevant after a temporal shift, either an activity or an object.

An interesting finding in Experiment 2 is the dissociation between the influence of temporal shifts on the availability of activity and object information. Specifically, while there was a temporal shift effect for the activity information, there was no such effect for the object removal condition. This suggests that the disruption of availability that is caused by the presence of a temporal shift is limited in scope. A temporal shift does not universally render information about prior, no-longer relevant aspects of a situation less available. Instead, the decline in availability appears to be limited to those aspects of a situation that help define a temporal framework, such as an ongoing activity, rather than those aspects of a situation that do not, such as entities that are involved in the situation. This is further reinforced by the fact that the correlation of the temporal framework establishment effect and the object maintenance and removal effects were of similar sizes and in the direction opposite that predicted by a view that assumes that all prior aspects of a situation become less available.

In general, it is again expected that Soldiers presented with information about a change in time are likely to be able to effectively process this information, although various dependent measures may not all be revealing. However, this is largely confined to the time framework itself, not in the ability to use that change in time information to adequately alter one's understanding of which components of the event will and will not continue to be relevant. Specifically, information about objects that were no longer relevant continued to be available in the situation models of people after a significant change in time had occurred and those objects could be inferred to be part of that event.

General Discussion

The aim of these experiments was to assess the degree to which different components of event updating can be observed with spatial and temporal shifts and to explore the interrelations among those components. What was observed was that although spatial and temporal updating did produce effects on the various updating components, not all components revealed such effects; that is, some measures seemed to indicate that no updating had occurred, whereas other measures showed clear influences. For example, there was a complete absence of an indication of spatial updating according to the reading time data, but a very clear influence according to the spatial framework probe data. More generally, this suggests that different types of updating have different consequences for the updating processes, and more research is needed to clearly understand what it means for a situation model to be updated, and the impact of such updating on the availability of different types of event information.

Furthermore, when the various components were directly compared, often no relation was observed among them. When relations were observed, they were often not of the quality that would be expected if the updating of one type were influencing the effectiveness of updating of another component. For example, framework updating was related to the availability of object information, but only generally. It was not tied to aspects of object information that would be

related to an event shift. If there are difficulties relating various updating components within an event dimension, this suggests that efforts to compare performance across dimensions may be problematic for similar reasons.

Even in the current research, when comparing spatial and temporal framework updating there were clear differences. As outlined in the introduction, there is reason to expect that these two types of updating will be similar. Specifically, in both cases people need to establish a new framework for the described events, and to manage the information about entities involved in them. However, similar measures produced very different results depending on the type of shift. The reading time data failed to produce any effect for the spatial shifts, whereas there was a clear effect for the temporal shifts. This may reflect the fact that people are more facile at processing spatial information (thereby showing less processing cost) than temporal information, which is known to be difficult for people to process and remember (e.g., Friedman, 1993). Conversely, the lower availability of removed object information following a shift was clearly observed following a spatial shift, but had no influence on performance following a temporal shift. The only measure to show a consistent influence across the two types of shifts was the availability of information that defined the spatial or temporal framework. This was the spatial location for spatial shifts and the activity information for temporal shifts.

Overall, this research illustrates that the representation and processing of event information is more complex than has been previously suggested. The process of updating the understanding of an event from a prior state to a new state can involve several well-defined components. However, not all of these components appear to be affected in the updating process. Moreover, when multiple components are identified as being affected by a change in a situation, the degree to which one component is affected appears to be unrelated to the degree to which the other components are affected. Finally, although there have been some studies suggesting that updating along one situation model dimension can influence the processing of information along another dimension, it is clear that this is a complex process, with different event dimensions involving different updating components.

For people who are constantly having to take in new information about how a situation is changing and developing, this research suggests that they will be largely successful at processing some aspects of these changes, but less so at others. When the action switches to a new spatial or temporal location, although they will likely have more difficulty with shifting over to a new time frame, in both cases information about what defines the new framework will be more available than what defined the old. That is, people are likely to have mentally moved on to the new situation. Information about objects and other entities that continue to be relevant is likely to remain available after these situations have changed and a person has mentally updated to the new set of circumstances. However, the story is more complex when it comes to knowledge about objects that were part of the old situation, but are not relevant to the current one. Specifically, while people are successful at decluttering their current stream of thought with information about objects in a prior spatial location, information about objects that were relevant in a previous period of time, but not the current one, will still be available. This continued availability of newly irrelevant information can take up mental resources, and possibly causes more general declines in performance (Hasher & Zacks, 1988). In sum, people engage a number

of mental processes to keep track of changes in dynamic situations. While they are likely to be effective in most of these cases, errors, especially in temporal updating, can occur.

Walking Through Doorways Causes Forgetting: Memory for Experienced Space

Abstract

We investigated the ability of people to retrieve information about objects as they moved through rooms in a virtual space. People were probed with object names that were either associated with the person (i.e., carried) or dissociated from the person (i.e., just set down). Also, people either did or did not shift spatial regions (i.e., go to a new room). Information about objects was less accessible when the objects were dissociated from the person. Furthermore, information about an object was also less available when there was a spatial shift; however, the spatial shift had a larger effect on memory for the currently associated object. These data are interpreted as being more supportive of a situation model explanation, following on work using narratives and film. Simpler memory based accounts that do not take into account the context in which a person is embedded cannot adequately account for the results. More broadly, this work suggests that people operating in complex spatial environments are affected by the structure of those environments and their interaction with them. First, people are less able to access information about objects with which they are no longer actively interacting. Second, and more importantly, moving from one spatial location to the next disrupts memory processing by making the availability of information about currently relevant objects less available. Because of the need for people to be effective in complex spatial regions, such as urban battlegrounds, this mental stumbling block needs to be addressed.

Introduction

The aim of this research is to understand how movement through space affects the ability to access information about objects with which people recently interacted. This assessment was done from a situation model perspective (Johnson-Laird, 1983; Van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). Situation models are mental representations that act as mental simulations that capture the functional relations among the entities in an event. Going beyond text comprehension, it is clear that as people operate in the world, they are trying to comprehend and understand what is going on around them. Part of this process is monitoring changes in space, and how these changes influence the availability of other information about the situation. Thus, we should be able to extend situation model theory to this set of circumstances as well. We used a strategy of taking what we know from situation model research in language and film and applied it to a situation in which a person is interacting with a virtual world.

One of the classic findings regarding situation models and spatial information was reported by Glenberg, Meyer, and Lindem (1987; see also Radvansky, Copeland, Berish & Dijkstra 2003; Radvansky, Copeland, & Zwaan, 2003). In this study people were presented with brief narratives to read in which an object was either associated with or dissociated from a protagonist, and then the protagonist moved to a new location. For example, a story protagonist could either put on (associated) or take off (dissociated) a sweatshirt and then go running. After the critical object was associated or dissociated, its identity was probed for using explicit measures, such as memory probes and the ability to answer probe questions about that object, as well as implicit measures, such as reading times for critical anaphoric sentences. Regardless of

the measure used, information about the critical object was less available when it was dissociated than when it was associated.

This pattern reflects the finding in the situation model literature that cognitive processing is disrupted by spatial shifts as people update their situation models. For example, people read more slowly when they encounter a spatial shift in a text (Zwaan, Magliano, & Graesser, 1995; Zwaan, Radvansky, Hilliard, & Curiel, 1998), take longer to retrieve information about an object the further away it is (Curiel & Radvansky, 2002; Morrow, Greenspan, & Bower, 1987; Rinck & Bower, 1995), and organize information by spatial regions, such as rooms (Radvansky, 1998; 1999; Radvansky, Spieler, & Zacks, 1993; Radvansky & Zacks, 1991; Zwaan, Langston, & Graesser, 1995), even when the situations are in narrative films (Magliano, Miller, & Zwaan, 2001).

Thus, when people are actively interacting in a situation, even if not reading about one, or viewing one in a narrative film, it is plausible to assume that their ability to access information will be affected by any spatial shifts they have made. This is because spatial shifts require people to update their understanding of the current situation. They need either to create a new situation model, or to meaningfully alter the one they are currently working with.

Alternative Views

However, having said this, there are a number of alternative views that would suggest that people may not be affected by spatial shifts that they themselves experience, such as would be the case in a virtual environment. First, although spatial shift effects have been observed in narrative comprehension, it is not unusual for these effects to fail to emerge (Radvansky & Copeland, 2000; Zwaan, Magliano, & Graesser, 1995; Zwaan et al., 1998; Zwaan & Van Oostendorp, 1993). This can occur when the space is relatively unknown, or is not emphasized by the text or the task. The absence of a spatial shift effect may occur because tracking spatial changes in a text is too difficult, and so people do not closely monitor everything that is going on. That said, however, work with narrative film, in which spatial shifts are much more dramatic, and more akin to the spatial shifts that would be experienced, show very large and clear spatial shift effects (e.g., Magliano et al., 2001).

A second alternative view is that when people are actually in a situation, because everything is readily available in the environment, updating space may be easy. The working memory load would be much lower than it would be in language comprehension. As such, we may not observe an updating effect because people are so facile at this sort of task.

A third possibility is that the results that are observed will conform to standard findings and theories of verbal memory that have been uncovered over the years, showing effects such as encoding specificity, recency, and so forth, and that the interaction with an ongoing situation that is nominally unrelated to the task at hand will have little influence.

Current Experiments

With these ideas in mind, we performed a series of studies to assess whether shifts in experienced space cause processing difficulties similar to those seen in language comprehension, or whether experienced space is processed differently than what has been observed in language processing. On this point, we have already reported some work showing that shifts in experienced space can affect performance (Copeland, Magliano & Radvansky, 2006; Magliano, Radvansky, & Copeland, in press). For example, when people play a video game from a first person perspective, shifts in space can by accompanied by decrements in performance, such as hitting enemy targets. However, these previous studies have not directly probed for the contents of memory in these ongoing situations.

The experimental task for this investigation was loosely based on the design of the Glenberg et al. (1987) study described earlier. Specifically, we had people move through a space, pick an object up in one room, move to the next room, set it down, pick up the next object, move to the next room, and so on. At various points during this process, people were given object name probes with the task of indicating whether it was an object they were currently carrying (associated condition), had just set down (dissociated condition), or was some other object. People were told to respond "yes" to associated and dissociated probes, but "no" to all other probes. Thus, at any given point in time, people needed to remember only two objects: the one they were currently carrying and the one they had just set down. This keeps the memory set size a very manageable two objects.

The expectation is that, if experienced situations are mentally represented and processed like those that are read about or viewed, people will be faster and more accurate to respond in the associated condition than in the dissociated condition. However, if this finding is limited to characteristics of verbal processing and memory, and interacting with an environment does not influence verbal memory for the names of objects, then no such difference will be observed.

Because it is impractical to have people actually move through a well-designed and large space, and real spaces do not afford the flexibility and control that one would like to have in an experiment, we had people moving through virtual spaces on a computer. There has been a blossoming of research using virtual reality to test ideas about cognition. Much of the foundational work that has been done has shown that the mental representation and processing of virtual spaces results in performance that is essentially identical to real spaces (e.g., Sun, Chan, & Campos, 2004) or with only small deviations (e.g., Waller, Loomis, & Haun, 2004). Thus, we expect that the experience of moving through our virtual spaces would be very similar to moving through a real space, with similar cognitive consequences.

Experiment 1

The aim of Experiment 1 was to assess whether the availability of object information would differ as a function of whether that object continued to be associated with a person after a spatial shift, or was dissociated from them prior to that shift. Of particular interest was whether these previously observed effects would also be observed in a desktop virtual reality environment similar to those observed in text comprehension, as predicted by situation model

theory (in terms of the need to update a model after a situational shift. The alternative is that spatial shifts of this sort would not have an influence on object availability in short-term memory, as would be predicted by more traditional models of memory.

Method

Participants. Forty-one people (15 female) were recruited from the University of Notre Dame subject pool and given partial course credit for their participation. The data from an additional 10 participants was lost, five for failing to follow instructions (they responded "no" to dissociated probes), four because of a programming error, and one stopped early because of motion sickness.

Materials and apparatus. The virtual spaces were created using the Valve Hammer environment creation program. This is the program used to create environments for the Half-Life video game. The virtual space was a 66 room environment in which all of the rooms were the same size. Included in each room was a rectangular table along one of the walls. On one end of the table was an object. This is the object the participant was to pick up. There was also an empty part of the table. This is the part where the object being carried by the participant from the previous room was to be set down. Each room had a different pattern on the walls to emphasize that there was a change in location. Furthermore, the two doorways in the room were never on the same wall.

The objects were made by combining colors and shapes. The colors used were: red, orange, yellow, green, blue, purple, white, gray, brown, and black. The objects were all regular geometric shapes: cube, wedge, pole, disc, cross (X), and cone. These types of objects were used to avoid the influence of strong semantic associations of the objects with the rooms they were in.

The displays were presented on a 66 inch diagonal rear projection SmartBoard using a PC-compatible computer.

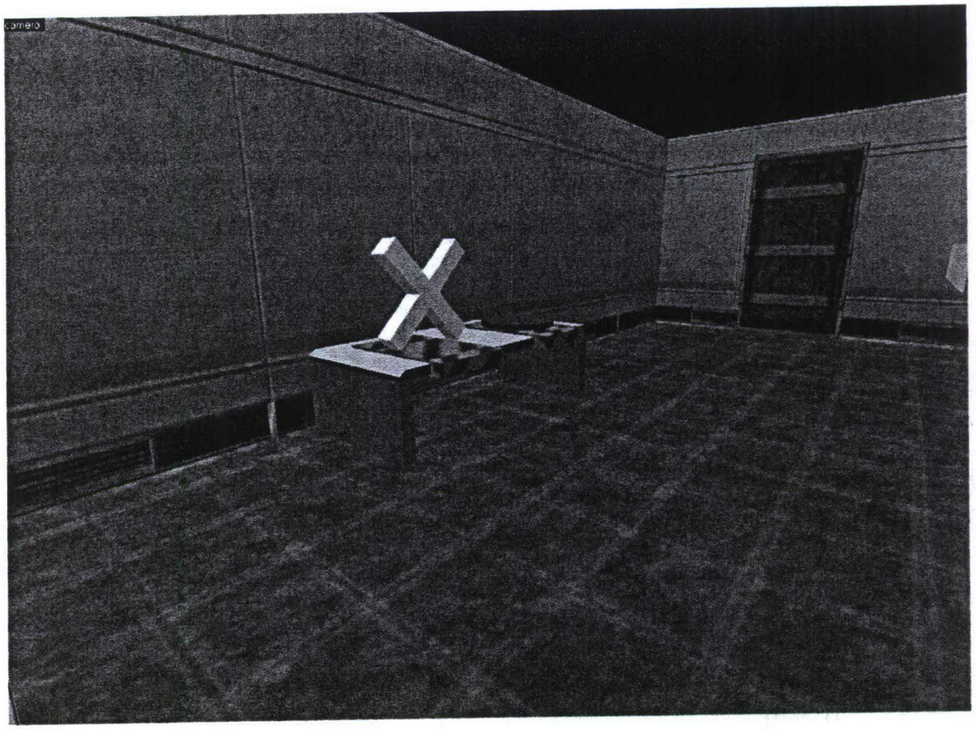

Figure 2.1. *A screen shot from one of the virtual environments.*

Procedure. After signing an informed consent form, people were seated about 1 meter in front of the large display screen. They were told that their task was to pick up an object from one room, go to the next room, place the object on the empty part of the table, then pick up the next object, proceed to the next room, and so forth. When an object was picked up, it disappeared from the screen. Thus, a person could not see the object they were currently carrying. When it was dropped off, it appeared on the table. Picking up and putting down objects was done simply by touching the appropriate end of the table. It did not matter which action (i.e., picking up and putting down) occurred first. An object was picked up or dropped off by simply approaching the appropriate end of the table. Subjects moved through the environment using the arrow keys on a computer keyboard using their left hand.

To make sure that participants progressed through the rooms in the required order, after a person entered a room, the door behind them closed. The door to the next room did not open until the person both placed the object down on the table and picked up the new one. The doorway to the next room required the person to turn away from the table in the current room.

There were 51 memory probe trials. Thus, not every spatial shift was accompanied by a memory probe. For the probe trials, upon entering a room, people were presented with a memory probe that consisted of a color and shape name. This probe appeared in the middle of the screen. Subjects were told to respond "yes" if the probe corresponded to either the object that was currently being carried (associated) or the one that had just been set down (dissociated). They were told to respond "no" to all other probes. "Yes" and "no" responses were made by pressing one of two buttons on a computer mouse (the left and right buttons were labeled with a "Y" and "N," respectively) that was held in the right hand. People moved using the left hand to press the

arrow keys. The up, down, left, and right arrow keys moved the person through the virtual environment forward, backward, left, and right, respectively. The negative probes were generated by recombining the object and color name for the associated and dissociated objects so that the task would not be too easy. For example, if the associated object was a white cube, and the dissociated object was a red wedge, a negative probe might be "red cube." Thirteen of the trials were probes for the associated object, 13 for the dissociated object, and 25 were negative probes. The experimental procedure typically lasted between 10 and 15 minutes.

Results

The response time and error rate data are summarized in Table 2.1. As can be seen, people responded more quickly and more accurately when the object was associated than when it was dissociated, $F(1, 40) = 38.37$, $MSE = 74679$, $p < .001$, and $F(1, 40) = 18.64$, $MSE = .018$, $p < .001$, for response times and error rates respectively. In addition, there was no difference in the pattern of response times between dissociated and negative probes, $F < 1$, but people were more error prone to dissociated probes than to negative probes, $F(1, 40) = 13.72$, $MSE = .027$, $p < .001$, which were no different than the associated probes, $F < 1$.

Table 2.1
Experiment 1: Response Times (in ms) and Error Rates (Proportions)

	Associated	Dissociated	Negative
Response Time	1440 (330)	1814 (484)	1814 (489)
Error Rate	.20 (.14)	.33 (.18)	.20 (.13)

Note. Standard deviations are presented in parentheses.

At this point we decided to examine this updating effect to determine whether this was a general effect, or whether there were interesting individual differences that could provide some insight into which conditions were being affected to produce our pattern of data. Specifically, we were interested in whether the size of the effect was due to differences in maintaining information about the associated object, or accessing information about the dissociated object. To this end, we performed a correlation on the size of the updating effect with the response times in the associated and dissociated conditions. What we found was that there was no relation for the associated condition, $r = -.09$, but there was a strong relation for the dissociated condition, $r = .74$, $p < .001$. Thus, the updating effect reflects a difficulty accessing information about a dissociated object rather than maintaining information about the associated object.

Discussion

The results of Experiment 1 illustrate the standard associated/dissociated effect that has been previously observed in the text comprehension literature (Glenberg et al., 1987). After a spatial shift, people responded quickly and more accurately when the object was associated with the person than when it had been dissociated. This suggests that people are actively monitoring the spatial characteristics of the dynamic situation, and that this is affecting the availability of information in memory. These results are inconsistent with views of memory that do not take

into account how a person is interacting with their environment and the structure of that environment. Even if people explicitly rehearse the names of the objects, there is a memory disruption.

Although there was a clear effect in Experiment 1, there is some ambiguity as to what is driving it. Specifically, it is unclear to what extent the observed effect is a result of the person monitoring what they are currently carrying, or to the spatial shift. In situation model theory, the associated/dissociated difference refers to the structural relations of the current situation, whereas the spatial shift refers to the spatial-temporal framework that defines events (e.g., Wyer & Radvansky, 1999). Thus, there are two components, according to situation model theory, that could be at work here producing this effect.

Experiment 2

The aim of Experiment 2 was to assess the degree to which the spatial effect observed in Experiment 1 was due to objects being either associated or dissociated with the person, and/or to a shift in space; these two components need to be broken apart and assessed separately. To this end, Experiment 2 was very similar to Experiment 1, except that sometimes the person walked through a doorway to another room before being probed, whereas the rest of the time the person walked across a large room toward a second table before being probed. The large rooms were created by tearing down the walls that divided some of the rooms. In all cases there were associated and dissociated objects. What varied was whether there was a spatial shift, allowing us to separate out the influence of these two factors.

In this experiment, the spatial distance traveled was essentially the same in the shift and no-shift conditions. Although this was controlled for here, it should be noted that previous work in narrative comprehension has shown that spatial distance traveled is less important than whether a spatial shift has occurred (Rink, Hähnel, Bower, & Glowalla, 1997). Thus, spatial distance is thought to play a minimal role in these sorts of situations.

Method

Participants. 54 people (26 female) were recruited from the University of Notre Dame subject pool and given partial course credit for their participation. The data from an additional 11 participants were dropped. Eight of these people failed to follow the instructions, the data from one were lost due to a programming error, and one person stopped early after reporting motion sickness.

Materials and procedure. The virtual spaces were again created using the Valve Hammer environment creation program, using the same apparatus and region creation guidelines. The virtual space for this investigation included two 53 room environments. Unlike Experiment 1, some of the rooms were large and some were small. In principle, what we did amounted to removing the walls and doorways separating rooms, thereby keeping distance the same, but varying whether a spatial shift occurred. As in Experiment 1, the walls of different rooms had different patterns whereas the walls within the same room all had the same pattern.

For the no-shift trials, to direct the person to the correct table, when a person first entered the large room, half of the room was darkened, and there was an invisible barrier that prevented them from going to the wrong part of the room with the incorrect table. No one reported awareness of the barrier. After the person dropped off the object on the correct table and picked up the next object, the second half of the room was brightened and the invisible barrier was deactivated. On the no-shift trials, a memory probe appeared when the person entered the second half of the room. Again, like the shift trials, not every instance of crossing to the second half of a room was accompanied by a memory probe.

After signing an informed consent form, subjects were seated in front of the display with the same instructions as for Experiment 1. For 15 trials, people did not make a spatial shift (resulting in 5 trials in each condition: associated, dissociated, and negative) and for 36 trials, there was a shift (with 12 trials in each condition: associated, dissociated, and negative). The experimental procedure typically lasted between 10 and 15 minutes.

Results

The response time and error rate data are summarized in Table 2.2. The response time and error rate data were submitted to 2 (shift vs. no-shift) X 2 (associated vs. dissociated) repeated measures ANOVAs. For the response time data, there was no main effect of shift, $F < 1$, but there was a significant main effect of associated/dissociated, $F(1, 53) = 17.95$, $MSE = 137022$, $p < .001$, replicating Experiment 1. Importantly, there was a significant interaction, $F(1, 53) = 4.33$, $MSE = 99367$, $p = .04$.

Table 2.2

Experiment 2: Response Times (in ms) and Error Rates (Proportions)

	Associated	Dissociated	Negative
No Spatial Shift			
Response Time	1433 (472)	1736 (567)	2033 (614).
Error Rate	.05 (.14)	.19 (.23)	10 (.19)
Spatial Shift			
Response Time	1558 (380)	1682 (478)	2041 (561)
Error Rate	.14 (.12)	.22 (.20)	.15 (.15)

Note. Standard deviations are presented in parentheses.

To understand this interaction, we broke the data down two ways. First, we considered the no-shift and shift conditions separately. Although the size of the associated/dissociated difference was larger for the no-shift (303 ms) than for the shift condition (124 ms), it was significant for both, $F(1,53) = 14.79$, $MSE = 167179$, $p < .001$, and $F(1,53) = 6.01$, $MSE = 69210$, $p = .02$, respectively. Second, we considered the dissociated and associated conditions separately. Although there was no difference in response time to dissociated probes, $F < 1$, for the associated probes, people took significantly longer (over 100 ms) to verify what object they were currently carrying if there had been a spatial shift, $F(1,53) = 6.01$, $MSE = 69623$, $p = .02$. Therefore, making a spatial shift disrupted processing of currently relevant information.

For the error rate data, there were significant main effects of shift, $F(1,53) = 11.52$, $MSE = .016$, $p = .001$, and condition, $F(1,53) = 19.71$, $MSE = .032$, $p < .001$, with people making more errors when there had been a spatial shift and when objects were dissociated from people, respectively. In addition, there was a marginally significant interaction, $F(1, 53) = 2.83$, $MSE = .016$, $p = .09$. We broke the error rate interaction down like the response time data. First, looking at the no-shift and shift conditions separately, although the size of the associated/dissociated difference was larger for the no-shift (.14) than for the shift condition (.08), it was significant for both, $F(1,53) = 18.24$, $MSE = .028$, $p < .001$, and $F(1,53) = 8.26$, $MSE = .020$, $p = .006$, respectively. Second, looking at the dissociated and associated conditions separately, there was no difference in error rates to dissociated probes, $F = 1.07$. However, for the associated probes, people made more errors (nearly three times as often) when verifying what they were currently carrying if there had been a spatial shift than if there had not been one, $F(1,53) = 20.99$, $MSE = .010$, $p < .001$. Once again, making a spatial shift disrupted processing of currently relevant information. Walking through doorways causes forgetting.

At this point, we again addressed some individual differences in the nature of this updating effect. First, there was no correlation between the size of a person's associated/dissociated and shift effects, $r = -.01$. This suggests that these two effects may reflect qualitatively different processes. Second, for the associated/dissociated effect, like Experiment 1, there was no relation for the associated condition, $r = -.24$, $p > .10$, but there was a strong relation for the dissociated condition, $r = .59$, $p < .001$. Thus, the associated/dissociated effect more reflects a difficulty accessing information about a dissociated object rather than maintaining information about the associated object. Third, in terms of the shift effect, there was a small relation for the shift condition, $r = .22$, $p = .11$, and a stronger relation for the no-shift condition, $r = -.486$, $p < .001$. Inspection of the scatterplots showed that larger shift effects were due to slower response times in the shift condition, and that smaller shift effects were due to processing difficulties some people had with the no-shift condition.

Discussion

The results of Experiment 2 replicated the associated/dissociated effect of Experiment 1 and previous studies (Glenberg, et al., 1987; Radvansky & Copeland, 2001; Radvansky et al., 2003), even when there was no spatial shift. Thus, there was an effect of an object being associated with or dissociated from a person that does not depend on spatial shifts occurring. Furthermore, there is an effect of making a spatial shift that exists apart from the associated/ dissociated effect. Specifically, there is fairly clear evidence that moving through a doorway from one region to the next makes information that would otherwise be highly available, less available. Information that is at a relatively low level of availability is less affected. This shows the different contribution of relational and framework information in situation model processing.

General Discussion

This work shows that the sorts of situation model updating effects that have been observed in text and film comprehension and memory extend to cognitive processes about virtual interactions with a situation. In this case, it was a virtual reality environment. Thus, there appears

to be a common set of cognitive processes for dealing with event information, regardless of whether that event is directly or indirectly experienced (e.g., Copeland et al., 2006).

In terms of the associated/dissociated effect, this investigation was able to replicate findings previously observed only in text processing work (Glenberg et al., 1987; Radvansky & Copeland 2001; Radvansky et al., 2003). This extends the idea that there are certain portions of a person's situation model that are foregrounded. These foregrounded elements are more available than are the other elements. What appears to be guiding this foregrounding process, in terms of spatial relations, is the degree to which there is a functional interaction between the person and the objects in the situation (Radvansky & Copeland, 2000). In this case, carrying an object provides a functional interaction between the person and the object; just having an object in the room that is not being carried does not provide such interaction.

In terms of the spatial shift effect, we were able to observe a clear influence of changing rooms. This is consistent with previous research on situation models showing that spatial shifts can disrupt processing. Furthermore, the ease with which these effects were observed, in contrast with the work on text comprehension, even in the absence of the need to attend to spatial shifts for the task, suggests that when spatial shift information is readily available in the environment, people are processing this information and incorporating it into their situation models of the world as they move from one place to another.

In some sense, the disruption of cognitive processing is expected. After all, we have repeatedly observed a cost to cognition when spatial shifts occur in text processing. However, in another sense, this result is quite surprising. Because we regularly move through space in our everyday experience, it might be reasonable to expect that we should have become quite facile at dealing with moving from one room to another. However, this was not what we observed. Instead, we found that moving through a doorway disrupted cognitive processing. This is made even more surprising by the fact that the memory probe task does not require tracking spatial information at all, and that the greatest memory accuracy deficit of moving through doorways was for objects that a person was currently carrying.

Alternative Explanations

One possible explanation of these results is that this is just another demonstration of the encoding specificity phenomenon (Thompson & Tulving, 1970). That is, when context changes, memory becomes worse. Although what we report here certainly has some affinity with this classic finding, there are a number of reasons to suspect that this is not the whole story. First, it should be noted that whereas encoding specificity effects are readily observed with free recall tasks, they are notoriously difficult to observe with recognition (Smith, Glenberg, & Bjork, 1978), such as was used here. Second, it should be noted that the currently carried object was in the new context; it was not associated exclusively with the old context. Finally, if what we are reporting were only an encoding specificity effect, it should have been observed for both the associated and dissociated objects. However, it was primarily concerned with the associated object. As such, an encoding specificity explanation of our data comes up short.

Another alternative explanation is that our findings do not reflect situation model processing, but may reflect simpler memory processes, such as those studied in more verbal learning oriented paradigms. Specifically, the current task, in some sense, is a verbal short-term memory task in which a person need only rehearse the names of the two objects and does not need to refer to the ongoing situation. We agree that this is something people could have done. However, the fact that a spatial shift effect was observed with such a small short-term memory load suggests that the structure of the situation is having a profound influence on performance, even on such a simple task. One would expect that in even more complex tasks, the structure of the situation would have a greater impact.

Another idea is that whereas the environment was filled with perceptual/visual/spatial information, the probes used were verbal. As such, there is a mismatch between what people are interacting with and what people are being probed with. However, we would argue that the observation of a spatial shift effect in the presence of such a mismatch also further strengthens our findings. Namely, we found an influence of the experience of a spatial shift disrupting the maintenance of verbal information. This is important in light of popular theories, such as Baddeley and Hitch's (1986) working memory model, in which verbal and visuospatial information are handled by separate systems. Such a theoretical view might predict that because different types of information are being processed by different aspects of working memory, there would be no influence of the one on the other. However, a clear influence was observed.

A final possibility is that the observed spatial shift effects may actually be a serial position effect. That is, the associated object was more available because it was more recent. However, this is not the case. Although the associated object is the most recent one in the series of objects, it is not the most recent one seen. That was the dissociated object. In these experiments, a person could not move to the next room until they had both picked up the associated object (which disappeared from view) and set down the dissociated object, which appeared on the table in the room. Thus, the last object seen was the dissociated object. As such, if there is a serial position advantage, with the most recently encountered object being more available, then there should have been a memory advantage for the dissociated object, not the associated object, as was observed in the current experiments.

Situation Model Updating

At this point, we think that the disruption in memory occurs as a result of moving through doorways because entering a new room is a major change in the current situation, and this requires a person to update their situation model of the environment. This is in line with the updating effects observed in research on situation model processing in the domains of text and narrative film comprehension (Curiel & Radvansky, 2002; Magliano et al., 2001; Morrow et al., 1987; Rinck & Bower, 1995; Zwaan et al., 1995; Zwaan et al., 1998). Situation model updating requires a relatively large amount of cognitive effort and coordination, which can slow processing down and allow for more errors to occur.

Clearly, more work needs to be done on the effect of changes in space on comprehension and memory. However, the current research provides a tantalizing taste of how considering our interaction with the environment influences our thinking process. That is, we are just beginning

to understand how our physical architecture interacts with our cognitive architecture, but we hope to build a more complete understanding as we progress through this line of research.

In terms of the performance of people operating in complex spatial environments, this research has clear and important implications. First, this work suggests that peoples' memories for information about objects that they are no longer interacting with will decrease. Second, and more important, when a person moves from one area to another (however that area is defined in the mind of the individual), this will disrupt their memory for information relevant to their current goals. It is possible that the more spatial shifts there are, the more disrupted thinking will become. This is critically important in situations where a person needs to make quick decisions and be on the alert for potentially harmful situations.

Moving Through Known Spaces: The Availability of Object Information

Abstract

Previous research on the narrative comprehension of events has shown that when people read about characters moving about in a well-known environment, the availability of information about objects in that environment follows a spatial gradient. This spatial gradient reflects greater availability of objects in the room the story protagonist is currently in, with objects in other rooms becoming less available as they become further spatially removed from the character's current location. The current research was an attempt to extend this to an interactive environment. People first memorized a map of a building in the same manner as done for narrative comprehension studies. Following memorization, people navigated a virtual simulation of the area that was memorized. During navigation, people were probed with object name pairs with the task of indicating whether the two objects were in the same room. The results revealed no spatial gradient. Instead, another pattern of responses was observed. Specifically, memory for objects in occupied locations was more available. Second, memory for objects along pathways (objects in a room that a person passed through but did not interacted with) that were not destinations was suppressed. Finally, this suppressing took time to develop and continued to develop over time. These findings suggest that, first, the performance of Soldiers operating in known areas cannot be predicted from research on event comprehension using language materials. Instead, how they perform in interactive situations requires actual interactions with the environment. Second, some knowledge of objects in the environment may actually be less available if the Soldier passes through a region without the goal of interacting with those objects.

Introduction

Successful performance in the world requires that people have information available from memory at the time it is needed. The current research is about the availability of knowledge about objects in space. More specifically, how does the interaction with an environment influence the availability of information about objects in a well-known space?

A person moving about in a complex spatial area is an event. A great deal of work on event cognition has come from situation model theory. A situation model is a mental representation of a real or possible world that serves as a mental simulation (Johnson-Laird, 1983; Van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). While much of the work on event comprehension and memory has been done in the domain of language comprehension, there have been some efforts to extend this theoretical framework to other areas (Copeland, Magliano, & Radvansky, 2006), including the areas of film comprehension (Magliano, Miller, & Zwaan, 2001), and interactive, virtual environments (Radvansky & Copeland, in press).

Spatial Gradient of Availability

The aim of this research is to assess how the availability of information about objects in a well known environment is affected by a person's current location within that environment. This is part of a broader effort to extend our knowledge of how people understand events and situation beyond the work that has been done in language comprehension (Copeland et al., 2006).

Previous research in narrative comprehension has shown that the availability of information in memory is affected by a story protagonist's current location (e.g., Bower & Morrow, 1990). In these studies, people first memorize a map of a building, along with the locations of objects in the various rooms of the building. After memorization, people are given a text to read that describes the motion of a protagonist doing various activities throughout the building. During reading, knowledge of objects in the building is probed somehow, either through explicit memory probes of pairs of objects (e.g., Morrow, Greenspan & Bower, 1987; Morrow, Bower, & Greenspan, 1989), or by assessing reading times to critical sentences that refer to single objects in the building (e.g., Rinck & Bower, 1995; Curiel & Radvansky, 2002).

These assessments are made after a story character has moved from one room (called the Source Room) through another (unmentioned) room (called the Path Room) to a third room (called the Goal Room). What is observed is that people are fastest to respond to objects that are in the Goal Room, slower to respond to probes in the Path Room, and in turn are slower to respond to objects in the Source Room, and even slower to respond to objects in some Other Room. This pattern of data is known as a *spatial gradient* of availability in that the further objects are from the protagonist's current location, the slower the response times.

This spatial gradient occurs regularly, even when the mental organization of space may be temporal rather than spatial (Curiel & Radvansky, 2002). The spatial gradient effect is largely governed by the number of rooms that are traversed, rather than a reflection of Euclidean distance (Rinck, Hähnel, Bower & Glowalla, 1997). However, there is a need for the reader to mentally track the protagonist through the building. Thus, the spatial gradient does not occur if the name of the protagonist is not included among the set of probe items when people are explicitly probed with pairs of object names (Wilson, Rinck, McNamara, Bower, & Morrow, 1993). Also, the reader needs to have extensive knowledge of the spatial layout prior to reading or the spatial gradient is not observed (Zwaan, Radvansky, Hilliard, & Curiel, 1998).

This research effort follows on recent theoretical ideas of embodied cognition, in the sense that how these situation models are structured and used reflects how peoples' bodies interacted with the environment (Glenberg, 1997). One implication of this perspective is that the situation models created from reading a text should be similar to the ones created by the active interaction with an environment. As such, virtual reality (VR) technology provides an ideal test bed for assessing these theoretical concepts. Recent research using VR technology and human spatial cognition has shown that people treat virtual spaces in a manner very similar to real spaces (e.g., Sun, Chan, & Campos, 2004; Waller, Loomis, & Haun, 2004).

The aim of the current research was to examine whether the spatial gradient found in research on text comprehension would be extended to a virtual environment. To this end, Experiment 1 was modeled on a previous text study by Morrow et al. (1987) in which the Path Room was not probed for. Rather than reading a narrative about a character moving about in the virtual environment, a person actively interacted with the setting. In Experiment 2 the same procedure was used except that a Path Room was now included. Finally, Experiment 3 was a replication of Experiment 2 except that a 2 second delay was added to allow people to mentally adjust to the new environmental context.

Experiment 1

In Experiment 1, participants memorized locations of rooms and objects in a map of a research center. After memorization, people navigated through a VR representation of this environment and were probed for the locations of pairs of objects at critical points. If the work in text comprehension reflects the processing of information in a manner that parallels that when an environment is actually experienced, then a spatial gradient should be observed with information about objects being most available in the room that a person is currently in and becoming less available as the objects become more distant from the person.

Method

Participants. Sixty-eight undergraduates were recruited from the University of Notre Dame and received partial class credit for their participation.

Materials and procedure. A map of a research center, used by Curiel & Radvansky (2002), with ten rooms and four objects in every room was memorized (See Figure 3.1). During memorization, participants viewed the complete map on a computer screen until they felt ready to be tested on the room names and object locations. After studying the map, a blank map was displayed with red squares in place of the objects. People typed the name of the object located at a particular square. This memorization procedure was used for all of the object locations, in a random order for each study cycle. After this test period, if any errors were made, then the original map was displayed again for studying. This study-test procedure continued until all the objects and their locations were correctly recalled twice.

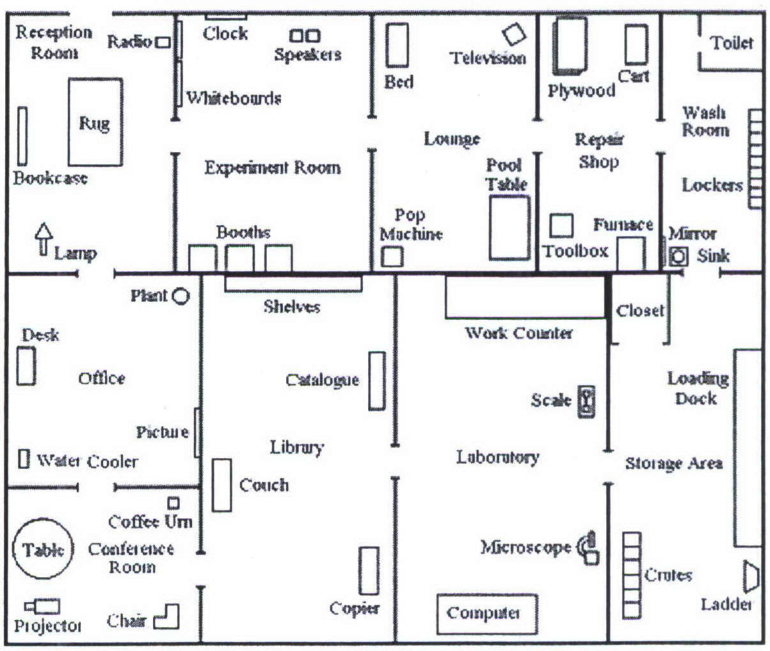

Figure 3.1. *Map of the building and object locations memorized by subjects.*

After the participant learned all of the objects and locations in the map they moved to a testing room to begin the movement phase of the experiment. A three-dimensional model of the research center was displayed. The virtual building was created using the Valve Hammer environment creation program. This is the program used to create environments for the Half-Life video game. A sample display is shown in Figure 3.2. Included in each room were the four objects from the study map. The displays were presented on a 66 inch diagonal rear projection SmartBoard using a PC-compatible computer. People were seated about 1 meter in front of the large display screen. They were told that their task was to first move about the building to see how the rooms corresponded to the map that they just memorized.

Figure 3.2. *Sample display showing a VR rendition of the building that was memorized.*

People first traveled all of the rooms of the building by using keys on a keyboard with their left hand, starting with the reception room. When people returned to the Reception Room they were given instructions to move to another room using the shortest path. After arriving in the goal room they were given instructions to move to another room. This pattern of instructing people to move to another room after arriving in a goal room continued until the end of the testing session. To make sure the participants progressed through the rooms in the required order, a warning sign appeared indicating that the person was traveling in the wrong direction if they happened to choose the long route to the goal room.

On critical trials, a pair of object names was presented on the screen, as shown in Figure 3.3. There were 48 memory probe trials. Not every spatial shift was accompanied by a memory probe, but participants were probed at least once during a three-move period. For the probe trials, upon entering a room, people were presented with a memory probe that consisted of a pair of

object names. One of the two objects was sometimes "Yourself" and participants were instructed to answer "Yes" if at that time they were in the room with the particular object. This was done because research in text comprehension has shown that if the story protagonist is not included among the objects probed, a spatial gradient will not be observed (Wilson et al., 1993). The probe appeared in the middle of the screen. The task was to indicate whether the two objects occupied the same room in the building or not. The negative probes were generated by combining two objects that were in different rooms. "Yes" and "no" responses were made by pressing one of two buttons on a computer mouse (the left and right buttons were labeled with a "Y" and "N," respectively) that was held in the right hand. The left hand was used to navigate the environment using arrow keys.

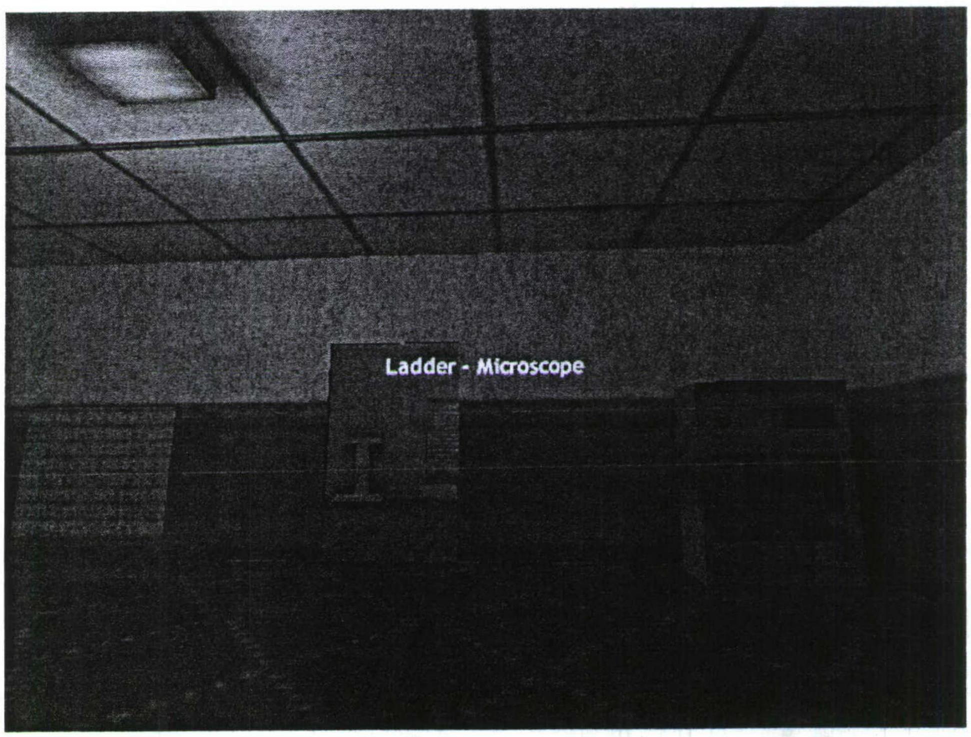

Figure 3.3. *An example of an object name pair probe used in the experiments.*

People moved about in the environment using their left hand to press the arrow keys. The up, down, left, and right arrow keys moved the person through the virtual environment forward, backward, left, and right, respectively. The experimental procedure typically lasted one hour.

Probe rooms were sorted into three categories: Goal, Source, and Other. In the Goal Room condition, people were probed for objects in the room they were currently in. The Source Room condition was the room the participants had just initiated their movement from. In the Other Room condition, participants were probed using two objects that were in any other rooms. For negative probes, people were given the names of objects from two different rooms.

Results and Discussion

Response times, presented in Table 3.1, were submitted to a 3-way repeated measures ANOVA as a function of the distance of the probe objects from a person's current location (i.e., Goal, Source, and Other). Response times greater than 5,000 and less than 500 were trimmed, followed by an individual sample size trim (see Van Selst & Jolicoeur, 1994). Planned comparisons of goal, source, and other conditions were conducted using planned comparisons.

Table 3.1.
Response Times (in ms) and Error Rates (in Proportions) for Experiment 1

	Goal	Source	Other
Response Times	2431 (585)	2223 (548)	2370 (509)
Error Rates	.17 (.19)	.12 (.14)	.13 (.13)

Note. Standard deviations are in parentheses.

For the response time data, there was a main effect of condition, $F(2,134) = 5.16$, $MSE = 149313$, $p = .007$. Planned comparisons revealed that the Goal and Source conditions were significantly different from one another, $F(1, 67) = 8.58$, $MSE = 169977$, $p = .005$, as were the Source and Other conditions, $F(1, 67) = 5.77$, $MSE = 125402$, $p = .02$. However, there was no difference between the Goal and Other room conditions, $F < 1$. Clearly, there is no spatial gradient evident in these data. This suggests that the availability of information in memory during active interaction differs from what is observed from research on language comprehension. Thus, work directly investigating interactive effects is necessary. Assuming that performance on the Other Room probes can serve as a control, the pattern of data observed here appear to show that there is some facilitation of object knowledge for those objects that are in the room that the person has just come from, and that the knowledge of objects in the Goal Room has not yet been meaningfully activated.

Error rates also are presented in Table 3.1, and were submitted to a similar 3-way ANOVA. There was a marginally significant main effect of condition, $F(2,134) = 2.60$, $MSE = .017$, $p = .08$. Planned comparisons revealed that the Goal and Source conditions were significantly different from one another, $F(1, 67) = 4.51$, $MSE = .018$, $p = .04$, but not the difference between the Source and Other conditions, $F < 1$, nor the difference between the Goal and Other room conditions, $F(1, 67) = 2.39$, $MSE = .020$, $p = .13$. Again, there is no spatial gradient. The errors are similar in the three conditions, although there were somewhat more errors in the Goal Room condition.

Experiment 2

Experiment 2 was intended to be a replication and extension of Experiment 1. The major difference between Experiment 2 and Experiment 1 was that the distance traveled between the Source and Goal room conditions was increased by including a Path Room, as has been done in many other studies. Thus, we can assess the availability of objects in a room that people have merely passed through. This will also increase the amount of time that has passed since the

person was last in the Source Room. This may allow the spatial gradient to emerge as has been observed in language comprehension studies. Alternatively, the results may more closely resemble those of Experiment 1, in which information about objects in the Source Room is more available, although this may decrease with the increase in delay time.

A point of interest here is what will be the availability of object information from the Path Room. There were three possibilities. The first is that because this is the room that people have just come from, memory for those objects will be more available, just as with the Source Room in Experiment 1. The second possibility is that because people are not stopping in the room, but merely passing through it, knowledge about objects in the Path Room will be unaffected. That is, they will be neither facilitated nor inhibited relative to the memory for objects in the Other Rooms. Finally, a third possibility is that, because a person is passing through the room, the person's presence in that room will activate the memories about the objects in this room. However, because this room is not the destination, this information is irrelevant with respect to a person's movement though the environment. As such, this would be prepotent but irrelevant knowledge. A typical fate for such strong but wrong information is that it is inhibited in memory (e.g., Hasher & Zacks, 1988; Radvansky, 1999). If it were the case that people were inhibiting this information, then it would be expected that people would respond more slowly to Path Room probes relative to the Other Room probes.

Method

Participants. One hundred-fifteen undergraduates were recruited from the University of Notre Dame and received partial class credit for their participation.

Materials and procedure. The materials and procedure for this experiment were the same as those for Experiment 1, except that on critical trials people moved through a Path Room on the way from the Source Room to the Goal Room.

Results and Discussion

Response times, presented in Table 3.2, were submitted to a 4-way repeated measures ANOVA as a function of the distance of the probe objects from a person's current location (i.e., Goal, Path, Source, and Other). Response times were trimmed and analyzed in the same manner as Experiment 1.

Table 3.2
Response Times (in ms) and Error Rates (in Proportions) for Experiment 2

	Goal	Path	Source	Other
Response Times	2224 (499)	2342 (579)	2227 (530)	2237 (585)
Error Rates	.13 (.13)	.15 (.17)	.13 (.14)	.14 (.14)

Note. Standard deviations are in parentheses.

For the response time data, there was a main effect of condition, $F(3,342) = 2.63$, $MSE = 140253$, $p = .05$. Planned comparisons revealed that the responses to the Path Room probes were slower than the Goal, Source, and Other conditions, $F(1,114) = 7.12$, $MSE = 1113403$, $p = .009$, $F(1,114) = 6.08$, $MSE = 124726$, $p = .02$, and $F(1,114) = 3.63$, $MSE = 172811$, $p = .06$, respectively. The differences between the Goal, Source, and Other conditions were not significant: all Fs < 1. Again, there is clearly no spatial gradient. Furthermore, the response time advantage for the Source Room probes observed in Experiment 1 is no longer present, suggesting that the increased delay before probing caused that information to become less available. Also, there is a clear inhibition effect for responses to the Path Room probes. This suggests that this information was salient in the environment, but was suppressed to keep it from intruding on the current stream of processing, consistent with an inhibition account. This likely occurred because the information in the Path Room was salient in the environment, because people were passing through it. However, this information was also irrelevant because people were not planning on interacting with the objects in that room. As such, the strength of the information about Path Room objects was such that it would have intruded on working memory processes. However, because it was irrelevant, it needed to be suppressed. This may have been done by an active suppression mechanism (e.g., Hasher & Zacks, 1988).

Error rates also are presented in Table 3.2, and were submitted to a similar 4-way ANOVA. The effect of condition was not significant, $F < 1$ with error rates being similar in all probe conditions. Again, there is no evidence of a spatial gradient.

Experiment 3

The results of Experiment 2 suggest that there is some inhibition of salient but irrelevant information for rooms that a person passed through, but did not spend any additional time in. The result of a decreased availability of Path Room information is somewhat surprising given that the person was just in that room. The aim of Experiment 3 was to replicate this effect, and to explore further ideas about what might be causing this phenomenon. Experiment 3 was done in an identical manner to Experiment 2 except that, after the person entered the Goal Room, there was a 2 second pause before the probe was presented.

One possibility is that the suppression effect observed in Experiment 2 is a transient effect. If so, then it would be expected to be smaller or absent in Experiment 3. The other possibility is that it is a more durable effect; in which case the suppression effect would be the same, if not larger, than in Experiment 2. This second possibility carries with it the possibility that there may be a suppression effect occurring for the Source Room as well. It was not observed in Experiment 2, however, because not enough time had elapsed. In that experiment the suppression may have started (which is why the facilitation observed in Experiment 1 was no longer present). If this were the case, then a suppression effect would be observed in Experiment 3 for the Source Room probes.

Method

Participants. Forty-four undergraduates were recruited from the University of Notre Dame and received partial class credit for their participation.

Materials and procedure. The procedure for Experiment 3 was similar to Experiment 2, except that there was a 2 second delay after the person entered the Goal Room prior to the presentation of the probes.

Results and Discussion

Response times, presented in Table 3.3, were submitted to a 4-way repeated measures ANOVA as a function of the distance of the probe objects from a person's current location. Response times were trimmed and analyzed in the same manner as Experiments 1 and 2.

Table 3.3.
Response Times (in ms) and Error Rates (in Proportions) for Experiment 3

	Goal	Path	Source	Other
Response Times	2096 (510)	2259 (465)	2267 (561)	2085 (519)
Error Rates	.14 (.14)	.14 (.14)	.12 (.12)	.09 (.14)

Note. Standard deviations are in parentheses.

For the response time data, there was a main effect of condition, $F\ (3,129) = 3.71$, $MSE =$ 118004, $p = .01$. Planned comparisons revealed that the responses to the Path and Source Rooms probes were responded to slower than the Goal Room probes, $F(1,43) = 6.16$ $MSE = 94278$, $p = .02$, $F(1,43) = 4.97$, $MSE = 129845$, $p = .03$, respectively, and the Other Room probes, $F(1,43) =$ 6.12 $MSE = 108445$, $p = .02$, $F(1,43) = 5.03$, $MSE = 145611$, $p = .03$, respectively. None of the other differences were significant: all Fs < 1. Again, there was no spatial gradient. The pattern of response times is consistent with a suppression account. Furthermore, the data suggest that the additional time given to process the information led to even more suppression, with a suppression effect emerging for the Source Room probes.

Error rates also are also presented in Table 3.3, and were submitted to a similar 4-way ANOVA. The effect of condition was not significant, $F\ (3,129) = 1.94$, $MSE = .015$, $p = .13$, with error rates being similar in all probe conditions. Again, there is no evidence of a spatial gradient.

General Discussion

The results of the research reported here show, quite clearly, that memory for information about objects in the environment is governed by different principles for interactive environments than for narrative environments. Specifically, although a spatial gradient is consistently observed in narrative memory for well-known object information from a previously memorized map, no hint of such an effect was observed in these three experiments. Instead, what was observed was some evidence for facilitation for knowledge of objects in rooms that a person had spent longer periods of time in, such as the Source Room in Experiment 1, and inhibition of knowledge for spatial locations that were salient, but irrelevant to the current task, such as the Path Rooms in

Experiments 2 and 3, and the Source Room in Experiment 3. Thus, in general the availability of knowledge is influenced by how a person is interacting with their environments.

These findings suggest that the results of other research that have successfully transferred effects for narrative comprehension to interactive experience (e.g., Radvansky & Copeland, in press) are limited. Special effort is needed to assess to what degree these other findings can be extended, and under which circumstances experience with interactive events will be different. More broadly, this research can be viewed as providing issues for theories of embodied cognition to work on. Specifically, why does work on narrative comprehension show such clear patterns of data that differs from data from interactive environments if people are using perceptual symbols and such to create analogs of actual experience?

In terms of the implications of this research for Army concerns, these findings are clear and important. Specifically, along with other work (e.g., Radvansky & Copeland, in press), these findings suggest that how a Soldier is interacting with their environment can affect the availability of information they need about that environment. In the work by Radvansky and Copeland (in press) it was found that making a spatial shift (e.g., moving from one location to another) reduces the availability of information, particularly for information relevant to a person's current goals. The current research extends these findings to show that information about spatial locations that were encountered in a transient manner may also render that information less available. This is critically important in situations where a soldier needs to make quick decisions and be on the alert for potentially harmful situations as they may miss important information about objects in the areas they are passing through, but are not part of their current destination.

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